QUARTERLY REPORT

(for January - March 1997)

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OCEAN OBSERVATIONS WITH EOS/MODIS
Algorithm Development and Post Launch Studies

by

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I shall describe developments (if any) in each of the major task categories.

1. Atmospheric Correction Algorithm Development.

a. Task Objectives:

During CY 1997 there are seven objectives under this task. Task (i) below is considered to be the most critical. If the work planned under this task is successful, a module that enables the algorithm to distinguish between weakly- and strongly-absorbing aerosols will be included in the atmospheric correction algorithm.

(i) We will continue the study of the "spectral matching" algorithm with the goal of having an algorithm ready for implementation by the end of CY 1997. As our work has shown that a knowledge of the vertical distribution of the aerosol is critical, if it is strongly absorbing, we have procured a micro pulse lidar (MPL) system for use at sea on validation cruises, and from islands (likely Barbados or the Canary Islands) in the Saharan dust zone, to begin to compile the climatology of the vertical distribution required to adopt candidate distributions for use in this region.

(ii) We need to test the basic atmospheric correction algorithm with actual ocean color imagery. We will do this by looking at SeaWiFS and OCTS imagery as they become available.

(iii) We must implement our strategy for adding the cirrus cloud correction into the existing atmospheric correction algorithm. Specific issues include (1) the phase function to be used for the cirrus clouds, (2) the details of making two passes through the correction algorithm, and (3) preparation of the required tables. These issues will be addressed during CY 1997 with the goal of having a complete implementation ready by the end of CY 1997.

(iv) The basic correction algorithm yields the product of the diffuse transmittance and the water-leaving reflectance. However, we have shown that the transmittance depends on the angular distribution of the reflectance only when the pigment concentration is very low and then only in the blue. We need to develop a method to include the effects of the subsurface BRDF for low-pigment waters in the blue.

(v) We will initiate a study to determine the efficacy of the present atmospheric correction algorithm on removal for the aerosol effect from the measurement of the fluorescence line height (MOD 20).

(vi) We will examine methods for efficiently including earth-curvature effects into the atmospheric correction algorithm. This will most likely be a modification of the look-up tables for the top-of-the-atmosphere contribution from Rayleigh scattering.

(vii) We will examine the necessity of implementing our out-of-band correction to MODIS.

b. Task Progress:

(i) We consider this task to be our most important atmospheric correction activity of 1997, and as such the major part of our effort on atmospheric correction will be focussed on it. During this quarter, we have further tested a "spectral matching algorithm" that, although very slow, is capable of distinguishing between weakly- and strongly-absorbing aerosols. It is based on combining a model of the atmosphere with a water-leaving radiance model for the ocean, and effecting a variation of the relevant parameters until a satisfactory fit to the MODIS top-of-atmosphere radiance is achieved. In simulations it showed significant success in detecting the absorption properties of the aerosol, i.e., distinguishing between weakly- and strongly-absorbing aerosols. Initially, we believed that the algorithm would also be capable of functioning in the same manner when aerosol vertical structure is an additional parameter. (Note that vertical structure is only important when the aerosol is strongly absorbing.) This quarter we have demonstrated that, at least in the first approximation, this is true, i.e., when simulations are performed using strongly-absorbing aerosols, and the candidate aerosol models include vertical structure, the algorithm still performs well. Finally, we are looking for ways to significantly increase the speed of the algorithm, and to enable it to operate using the same set of lookup tables that the basic algorithm requires. This would enable us to incorporate the "spectral matching" algorithm in the basic correction algorithm, to be called each N x N pixels (where N~10-100) to insure that candidate aerosol models with the correct properties are being used by the basic algorithm.

(ii) Some imagery has been acquired from the OCTS and we are preparing to test the performance of the algorithm in its present state.

(iii) None. This task has been put on hold to free resources for examination of task (i).

(iv) No work was carried out on this task.

(v) To study the efficacy of atmospheric correction of the fluorescence line height, we require a set of lookup tables specific to the relevant spectral bands. These required about 14,000 radiative transfer simulations. These tables are being prepared for our basic aerosol models.

(vi) No work was carried out on this task.

(vii) The specifics on incorporating the out-of-band corrections in the

MODIS algorithm have been worked out.

c. Anticipated Activities During the Next Quarter:

(i) We will continue testing the "spectral matching" algorithm. Of particular interest will be finding ways to make it faster, and to enable it to use the same lookup tables as the basic algorithm. Also models appropriate to specific aerosols, e.g., Saharan dust, etc., need to be developed. As described under major task number 5 below, we plan to operate our MPL system on Barbados to begin to understand the vertical distribution of Saharan dust.

(ii) As more OCTS imagery is acquired, we shall continue testing the algorithm.

(iii) None. The cirrus cloud issue in the presence of our "spectral matching" method needs to be explored. We will resolve the "spectral matching" questions first.

(iv) None.

(v) We will perform a basic test of the efficacy of the correction algorithm for retrieving the fluorescence line height.

(vi) None.

(vii) None, until we are provided with the final MODIS spectral response functions.

d. Publications:

H.R. Gordon, T. Zhang, F. He, and K. Ding, Effects of stratospheric aerosols and thin cirrus clouds on atmospheric correction of ocean color imagery: Simulations, Applied Optics, 36, 682--697 (1997).

2. Whitecap Correction Algorithm (with K.J. Voss)

As the basic objectives of this task have been realized, work is being suspended until the validation phase, except insofar as the radiometer will be operated at sea when sufficient number of personnel are available. Karl Moore, the post doctoral associated who was responsible for the operation of the instrument and the data analysis, has accepted a position at the Scripps Institution of Oceanography. In his absence our goal is to maintain experience in operating and maintaining the instrumentation in preparation for the validation phase of the contract.

a. Near-term Objectives:

Operate the radiometer at sea to maintain experience in preparation for the validation phase.

b. Task Progress:

The radiometer was operated during a February cruise with Dennis Clark off Hawaii. From the standpoint of whitecaps this was a very good cruise (high winds) and we collected a large amount of whitecap data. At this time we have reduced the calibration data, but not the cruise data.

c. Anticipated Activities During the Next Quarter:

We will work to reduce the cruise data during this period, but it is a lower priority than the analysis of other data collected during this cruise.

d. Publications: Two papers are in the review process.

3. In-water Radiance Distribution (with K.J.Voss)

The main objective in this task is to obtain upwelling radiance distribution data at sea for a variety of solar zenith angles to understand how the water-leaving radiance varies with viewing angle and sun angle.

a. Near-term Objectives: None this quarter.

b. Task Progress: None

c. Anticipated Activities During the Next Quarter:

We acquired upwelling radiance distribution data with the RADS camera system during a cruise with Dennis Clark during November. It was very windy during this cruise, but data were acquired in the configuration expected to be used during validation cruises. We have finished the post-cruise calibration of this instrument. We will be reducing this data after the work with the Sky camera data reduction procedure is completed. We will be completing the calibrations and reducing data acquired during the cruise. We are also planning on making some minor changes to the instrument to improve its operation at sea.

d. Publications: None.

4. Residual Instrument Polarization.

The basic question is, if the MODIS responds to the state of polarization state of the incident radiance, given the polarization-sensitivity characteristics of the sensor, how much will this degrade the performance of the algorithm for atmospheric correction? We have developed a formalism which provides the framework for removal of instrumental polarization-sensitivity effects, and an algorithm for removing much of the error induced by the polarization sensitivity.

a. Near-term Objectives:

Add a module to perform the correction for residual instrument polarization.

b. Task Progress: None

c. Anticipated Activities During the Next Quarter:

We expect to deliver this module to R. Evans during the next quarter.

d. Publications: A paper is in the review process.

5. Pre and Post-launch Atmospheric Correction Validation and Vicarious Calibration/Initialization (with K.J. Voss)

a. Task Objectives:

The objectives of this task are three-fold:

(i) First, we need to study aerosol optical properties over the oceans to assess the applicability of the aerosol models used in the atmospheric correction algorithm. Effecting this requires obtaining long-term time series of the aerosol optical properties in typical maritime environments. This will be achieved using a CIMEL sun/sky radiometer that can be operated in a remote environment and send data back to the laboratory via a satellite link. These are similar to the radiometers used by in the AERONET Network.

(ii) Second, we must be able to measure the aerosol optical properties from a ship during the initialization/calibration/validation cruises. The CIMEL-type instrumentation cannot be used (due to the motion of the ship) for this purpose. The required instrumentation consists of an all-sky camera (which can measure the entire sky radiance, with the exception of the solar aureole region) from a moving ship, an aureole camera (specifically designed for ship use) and a hand-held sun photometer. Our objective for this calendar year is to make measurements at sea with this instrumentation, both to collect a varied data set and to test the instrumentation and data reduction procedures. We are working on the data reduction procedures to allow measurements to be reduced in almost real time (each night) so that alumcantor and principal plane measurements can be obtained quickly.

In the case of strongly-absorbing aerosols, we have shown that knowledge of the aerosol vertical structure is critical. Thus, we need to be able to measure the vertical distribution of aerosols during validation exercises. This will be accomplished with ship-borne LIDAR. We have procured a LIDAR system and modified it for ship operations. Our goal for this quarter was to successfully operate it on a ship.

(iii) The third objective is to determine how accurately the radiance at the top of the atmosphere can be determined based on measurements of sky radiance and aerosol optical thickness at the sea surface. This requires a critical examination of the effect of radiative transfer on ``vicarious'' calibration exercises.

b. Task Progress:

(i) During the last year we were operating the CIMEL in it's location in the Dry Tortugas. In October this instrument was removed for recalibration. At the same time the AERONET network, run by B. Hobren, decided to upgrade the CIMEL instruments with more stable interference filters and small hardware changes. We will be reinstalling this instrument when it is returned from NASA.

(ii) The sky camera system and aureole system was used on a cruise with Dennis Clark off of Hawaii (during February). Dennis Clark's group provided the sun photometer data. In addition to participating on the cruise we performed calibration of all the systems pre and post cruise. We are currently rewriting the data reduction programs for the sky radiance distribution system to allow data reduction to take place at sea, to speed this process. In addition, this is giving an opportunity to review this process and to perform tests of this data. We have reduced the aureole data from the first two cruises, and are currently evaluating this data.

To address the problem of vertical distribution of aerosols we have acquired a Micro Pulse Lidar from SSEI.   We have constructed a weather proof box for the instrument and this system was used for the first time during the February cruise with Dennis Clark. It performed well during this test, but a couple of modifications to its operation are being performed now. In particular the computer supplied with the system has had problems. These have been solved. We are now learning how to process the data from the LIDAR, and have started to look at the data collected during the February cruise.

(iii) We have completed a study of the accuracy with which one can compute the radiance at the top of the atmosphere from sky radiance measurements made at the sea surface. The results suggest that the bulk of the error is governed by the uncertainty in the sky radiance measurements. Furthermore, as it was shown that the largest error in the radiative transfer process was the error due to the use of scalar radiative transfer theory, we developed a an inversion/prediction method using vector theory. We find that it is possible to predict the polarization state of the top-of-atmosphere radiance quite accurately from surface measurements. This may be very important for validating the pre-launch polarization-sensitivity characterization of MODIS.

c. Anticipated Activities During the Next Quarter:

(i) We will be reinstalling the CIMEL in the Dry Tortugas at the first opportunity after its return from NASA. We are also working on a better method of acquiring the data through NASA. This will enable us to look at the sky radiance data in a more timely manner.

(ii) We will finish the data reduction work with the sky camera system in the next quarter. We are also reworking portions of this system to allow more automation of the data collection, and to fix minor problems which developed during the last cruise (specifically overheating of the system computer and corrosion on the computer backplane). The reduced aureole data will be merged with the sky radiance data to provide a complete sky radiance distribution during this next period. We will also finish reducing all of the aureole data during this next period.

We are presently making modifications to the LIDAR system. In particular we are:

1) Adding a tilted front window to the case to allow water to run off more easily and avoid retroreflection problems.

2) adding access panels to the Lidar box to enable us to check cabling and other system problems more easily.

3) acquiring a notebook computer to allow the LIDAR to be operated from this rather than a large desktop. This will significantly reduce the shipping required for the system.

(iii) None.

d. Publications: Three papers are in the review process.

6. Detached Coccolith Algorithm and Post Launch Studies (with W.M. Balch)

a. Near-term Objectives:

The algorithm for retrieval of the detached coccolith concentration from the coccolithophorid, E. huxleyi is described in detail in our ATBD. The key is quantification of the backscattering coefficient of the detached coccoliths. Our earlier studies focussed on laboratory cultures to understand factors affecting the calcite-specific backscattering coefficient. A thorough understanding of the relationship between calcite abundance and light scatter, in situ, will provide the basis for a generic suspended calcite algorithm. As with algorithms for chlorophyll, and primary productivity, the natural variance between growth related parameters and optical properties needs to be understood before the accuracy of the algorithm can be determined. To this end, the objectives of our coccolith studies during this last quarter have been to a) perform the last of a series of flow cytometry experiments examining the calcite-specific backscattering coefficient of calcite particles sampled in the field, and b) work up data from our pre-launch cruise in the Gulf of Maine last June.

b. Task Progress:

Background

The algorithm for retrieval of the detached coccolith concentration from the coccolithophorid, E. huxleyi is described in detail in our ATBD. The key is quantification of the backscattering coefficient of the detached coccoliths. Our earlier studies focussed on laboratory cultures to understand factors affecting the calcite-specific backscattering coefficient. A thorough understanding of the relationship between calcite abundance and light scatter, in situ, will provide the basis for a generic suspended calcite algorithm. As with algorithms for chlorophyll, and primary productivity, the natural variance between growth related parameters and optical properties needs to be understood before the accuracy of the algorithm can be determined. To this end, one of the objectives of our coccolith studies have been to define the effect of coccolithophore growth rate on:

1) the rate that coccoliths detach from cells (which also is a function of turbulence and physical shear)

2) rates of coccolith production

3) morphology of coccoliths

4) volume scattering and backscatter of coccoliths

We also have been examining the variability in the field of backscattering due to suspended calcium carbonate.

For perspective on the directions of our work, I provide an overview of our previous activities. During 1995, we focussed on all of the above objectives using chemostat cultures (in which algal growth rate is precisely controlled). During the latter half of 1995, our work focused on shipboard measurements of suspended calcite and estimates of optical backscattering as validation of the laboratory measurements. We participated on two month-long cruises to the Arabian sea, measuring coccolithophore abundance, production, and optical properties. During the first half of 1996, we focused again on objectives 2 and 4, during two Gulf of Maine cruises, one in March and one in June. During the second half of 1996, we participated on another cruise to the Gulf of Maine, and addressed objectives 2 and 4.

b. Task progress:

1) All suspended calcite samples from our November '96 cruise have now been processed on the graphite furnace atomic absorption spectrometer.

2) We have continued our assembly of the Arabian Sea and Gulf of Maine cruise optical data. While laborious, the object has been to organize all the data relating to calcite standing stocks, calcification rates, and optics, on to the same spread sheet such that we can then look at cross correlations between calcite concentration vs. a) coccolith concentration, b) coccolithophore concentrations, c) calcification rates, d) acid-labile backscattering, e) chlorophyll concentrations, etc.

3) Most of the time during this last quarter, I have spent preparing our data sets from previous flow cytometer experiments in order to write a synthesis paper on calcite-specific backscattering by coccolithophores. Several parts of the paper are now written. The suspended calcite samples for the last flow cytometer experiment from fall '96, tare being run as of this writing.

c. Anticipated Activities During the Next Quarter:

1) The underway data from the Gulf of Maine will be merged with our calibration measurements (vicarious calibrations are periodically made at sea and these data must be processed to verify whether instrument calibrations changed).

2) Hydrographic plots of the Gulf of Maine data will be made in which light scattering and chlorophyll are plotted in temperature salinity space.

3) We will be participating in a MODIS pre-launch cruise in the Gulf of Maine (June '97). We will be visiting 60 stations, performing measurements of total backscattering, acid-labile backscattering, calcite concentrations, coccolithophore and coccolith counts. These measurements will be made at discrete depths as well as continuously as the ship steams (surface only) We will also have the Yentsch/Phinney group on board measuring spectral absorption, upwelling and downwelling irradiance using a SATLANTIC bio-optical sampler.

d. Publications:

Balch, W. M., J. J. Fritz, and E. Fernandez. 1996. Decoupling of calcification and photosynthesis in the coccolithophore Emiliania huxleyi under steady-state light-limited growth. Marine Ecology Progress Series. 142: 87-97.

Fernandez, E., J. J. Fritz and W. M. Balch. 1996. Growth-dependent chemical composition of the coccolithophorid Emiliania huxleyi in light-limited chemostats. Submitted. J. Exp. Mar. Biol. Ecol. 207: 149-160.

Fritz, J. J. and W. M. Balch. 1996. A coccolith detachment rate determined from chemostat cultures of the coccolithophore Emiliania huxleyi. J. Exp. Mar. Biol. Ecol. 207: 127-147.

Balch, W., M. and K. A. Kilpatrick. 1996. Calcification rates in the equatorial Pacific along 140oW. Deep Sea Research. 43: 971-993.

OTHER DEVELOPMENTS

The PI participated in the MOCEAN meeting in Miami in January, and met with A. Fleig and K. Yang of SDST regarding MODIS Ocean test data sets.